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U. S. Naval School of Aviation Medicine



U. S. NAVAL AIR STATION
PENSACOLA, FLORIDA

RESEARCH REPORT



LOCALIZATION ACCURACY RESULTING FROM

ISOLATED BINAURAL STIMULATION

PROJECT No. NM 001 064.01.15

U. S. Naval School of Aviation Medicine 5 January 1953

Joint Report NM 001 064.01, Report No. 15

LOCALIZATION ACCURACY RESULTING FROM ISOLATED BINAURAL STIMULATION

Gilbert C. Tolhurst, Ph.D., Acoustic Laboratory, U. S. Naval School of Aviation Medicine, Pensacola, Florida

8 pp. 2 tables 2 illustrations UNCLASSIFIED

Judgments of apparent azimuth of the source of 5 different types of sound stimuli were made by 250 young adults, 30 judgments each. The subjects, in groups, listened over an isolated dual-channel system using split headsets to a single sound source. In effect this eliminated visual, muscle tonus and proprioceptive muscle cues. Subjects were unable to localize the 5 sound types better than chance within a quadrant of ± 45 degrees, except music. There were significant differences between localization frequency when the "correct" criterion was ± 90 degrees. The subjects made judgments, at a highly significant level better than chance, that the sound source was exactly 180 degrees from the stimulus.

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U. S. NAVAL SCHOOL OF AVIATION MEDICINE
NAVAL AIR STATION
PENSACOLA, FLORIDA

JOINT PROJECT REPORT NO. 15

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The Bureau of Medicine and Surgery Project NM 001 064.01.15

LOCALIZATION ACCURACY RESULTING FROM ISOLATED BINAURAL STIMULATION

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Commanding Officer

5 January 1953

Opinions or conclusions contained in this report are those of the author. They are not to be construed as necessarily reflecting the view or the endorsement of the Navy Department. Reference may be made to this report in the same way as to published articles noting author, title, source, date, project number and report number.

SUMMARY

Two hundred and five observers in groups made judgments of apparent azimuth of five different types of sound stimuli, 6 five-second presentations of each sound were heard over a dual-channel stereophonic system. The microphones were mounted on a turntable capable of being rotated through 360 degrees and separated to simulate intra-aural distance. This had the effect of being able to rotate an observer 360 degrees in relation to a single sound source, or the sound source rotating around the individual through 360 degrees. The observers made their responses on a prepared form indicating by a vector arrow the direction from which the sounds appeared to come as the angle of the microphone turntable was varied randomly in relation to a single loudspeaker. The distance also varied in four steps randomly from 8 inches to 3½ feet.

CONCLUSIONS

The analysis of the data indicate that observers attempting to localize sound stimuli presented by a dual-channel sound system:

1. Were unable significantly better than chance, to localize in azimuth within a full quadrant of ± 45 degrees the five types of stimuli when all were considered as a unit. However, the observers were able to localize Music within a quadrant better than chance responses.
2. Subjects were unable to localize one of the sounds used as stimuli within a quadrant of azimuth significantly better than any of the others.
3. By increasing the "correct" azimuth angle to include ± 90 degrees the observers were able to localize some of the stimulus sounds significantly different than others.
4. Sixteen percent of all responses made were 180 degrees away from the stimulus sounds. This judgement was significant well beyond the 0.1 percent level of confidence and indicates that there may be localization, that is, confusion, whether the stimulus is in one direction or directly opposite.

INTRODUCTION

The problems of sound localization have received attention by many investigators over a considerable period of time (2, 3, 5, 6, 9). The present theories seem to indicate that localization is a complex integration of intensity, temporal, and phase differences at the two ears. Additional cues are probably present resulting from visual stimuli and/or proprioceptive muscle tonus (8). Observations have also been made that complex tones are more easily and reliably located than are pure tones.

Many of the investigations using electronic devices have employed dichotic and binaural stimulation varying one or more of the above-mentioned "fundamental" factors of the elements of sound hypothesized as necessary for localization. Stevens and Newman have shown that localization error increases with the frequency of pure tone up to 3000 cps, then decreases to a low level at 10,000 cps. They also show there is a confusion between front and rear, particularly for frequencies below 3000 cps (7). They used the technique of outdoor free-field conditions swinging the sound source around the observer at a constant radius.

Earlier, Steinberg and Snow had experimented with the "stereophonic" effect, or auditory perspective, using two or more microphones and loudspeakers with the sound source (speech) behind an auditorium curtain and the observers in the house. They found reasonably good correspondence between the caller's actual position and his apparent position on the stage (4). The auditory effects of a two-channel system, having two microphones mounted on a dummy head in the position of the ears and the channels isolated to two earphones are strikingly realistic (1).

The present investigation is due to the influence of an experience with a high-fidelity two-channel system. The apparent positiveness with which a casual observer seemed to locate sound sources within a room plus the dramatic semblance of movement proposed the question of how accurate would the localization of various sounds be with the cues of vision, body movement and muscle tonus eliminated.

A statement of the problem would seem to be, to investigate the accuracy of binaural localization using five different types of sound stimuli presented to the ears by an isolated dual-channel system matched throughout. Under the conditions of the present experimental techniques the working hypotheses are:

1. Observers will not be able to indicate azimuth of a sound source within ± 45 degrees at better than chance frequency.
2. There is no difference among the five sounds used as stimuli when the criterion measures are the frequency with which observers indicate azimuth within ± 45 degrees, (also within ± 90 degrees).
3. There is no direct reversal (180 degree displacement) of observer's judgments.

EQUIPMENT

Figure 1 is a block diagram of the dual-channel sound system, each channel isolated, with the output going to each earphone of matched headsets at the observer's stations located in a soundproofed room. The minimum ambient noise level in the room was 46 db (C scale on the General Radio sound level meter).

The stimulus sounds were recorded on a magnetic tape recorder (Ampex 400) and were played back upon the same machine. This recorder was located in a control room and fed a 12-inch loudspeaker (Western Electric 728-B in an enclosed 3 cubic foot baffle) located in a small sound-proofed room. The loudspeaker was mounted so that the center of the speaker cone was at the same height above the horizontal as the dual microphones and delivered an average signal of 78 db, or $.0002 \text{ dynes/cm}^2$, at 8 inches. The two condenser microphones (Altec 21-B) were mounted on a brass turntable 5 inches apart, simulating inter-aural distance. The turntable rode two traverse rods parallel to the horizontal. This allowed the microphones to be rotated through 360 degrees and to move in a straight line from the axis of the speaker cone a distance of 8 inches minimum to $3\frac{1}{2}$ feet maximum. The loudspeaker-microphones relationships are shown in Figure 2. The microphones led to two matched pre-amplifiers in the console (Altec 350-A), located in the control room, which passed the signals to two "identical" amplifiers (Stancil-Hoffman R-48-P). Each amplifier drove one of the earphones (ANB-H-1) in each of the fifteen headsets located in the larger sound room at the observer's stations. The signal under the earphone cushions as measured by a probe tube coupled to a calibrated condenser microphone was 80 db when the microphones were 8 inches from the loudspeaker.

In essence, the signals were presented by a single sound source picked up by two microphones, each amplified by an identical amount and presented to separate earphones. The system was so arranged that when the pointer on the turntable was aimed along the axis of the loudspeaker, pointing toward the loudspeaker, the microphone on the right, or 90 degrees, fed the channel leading to the right ear of the observer. The microphone on the left, or 270 degrees, fed the left earphone. The S/N ratio of the total system was 21 db at the stimulus level used.

PROCEDURE

Two hundred and five young adults acted as observers in groups of 4 to 15 individuals per group, listening in quiet. Each observer made judgments concerning five different types of sound stimuli and each type of sound was presented six times for five seconds duration each presentation. Between each five second stimulus there was a five second silent period. Each series of like sound stimuli (one line on the response sheet) was announced, telling the type of sound stimulus to follow.

The microphones were switched off at the control room after the

initial announcement of each line and between each five second stimulus. This allowed an experimenter in the smaller sound room to rotate the microphone turntable to a designated azimuth angle and to vary the distance in relation to the loudspeaker to one of four positions, i.e. 8 inches, 1 foot, 2 and $3\frac{1}{2}$ feet. The azimuth and distance varied in a random order for each type of sound. The schedule is found in Appendix I. The five types of sounds used as stimuli were: (1) 500 cps pure tone; (2) sustained vowel [a] 125 cps sung by a male, baritone voice; (3) continuous speech, a paragraph of factual prose; (4) musical passage of full orchestra, symphonic arrangement of "Little Brown Jug"; (5) white noise.

Each group of observers received instructions to assure that the proper earphone went to the "correct" ear. Each individual was checked for earphone orientation. The directions for the use of the response form, (see Appendix II), were informally presented but always contained essentially the following information:

"You are going to hear 5 different types of sounds. Each of the five sounds you will hear six times and each will last 5 seconds each presentation. Notice on your response sheet (see Appendix II) that there is a representation of a head for every time you hear a sound. These 'heads' are supposed to represent your head, looking down from on top and facing in the same direction you are facing. The bump toward the top of the page you are to imagine as your nose. The two bumps on either side of the 'heads' are supposed to be your right and left ears respectively. The dot in the center represents the top center of your head. The sounds you will hear (these were enumerated) may appear to be coming from various directions, in front, behind or from the sides. Will you indicate by a line, or arrow, the direction from the center of your head, i.e. the dot, from which the sound appears to come. If the sound seems some distance from you make your arrow longer than if the sound seems closer. If the sound appears to stay inside your head and you cannot assign a direction to it, draw a circle around the dot. For each line of heads the recorded voice will tell you the type of sound you are to listen for. Use a new 'head' for your direction judgment each time you hear a five second sound".

Several illustrations of the use of the vector arrow to report azimuth judgments were given to each group. Preliminary experimentation had indicated that it was difficult for "naive" subjects to make both direction and distance judgments so that the observers were told to ignore attempting to fill in the "feet and inches" blanks on the response form and to respond to distance changes if they could, using the rough indication outlined in the "directions" above.

DATA

Four tabulations were made from the responses. These are found in Table 1 showing the frequency as well as the mean frequencies with which the judgments of the 205 observers, each making 30 responses, fit one of the four categories that were employed in testing the hypotheses.

Chi square tests were run to determine if the frequencies with which the observers made "correct" responses within ± 45 degrees were made better than chance. The individual chi square tests made for each of the five types of sound stimuli showed that Music had a value of 5.77 which is significant at the 2 percent level. This was the only significant value; the next largest chi square fell somewhere between the 20 - 30 percent level.

Two analyses of variance were formulated from the data. The first matrix used as basic scores the frequencies that each individual was able to indicate "correct" azimuth with ± 45 degrees for each of the five types of sound stimuli. The second analysis used as basic scores the frequency that each response judgment fell within ± 90 degrees. Both analyses are summarized in Table 2. Since each matrix had the same degrees of freedom that column is common for both.

Table 2

<u>Source of</u> <u>Variance</u>	<u>Sum of</u> <u>Squares</u>	<u>Sum of</u> <u>Squares</u>	<u>d.f.</u>	<u>Variance</u>	<u>Variance</u>	<u>(F)</u>	<u>(F)</u>
	$\pm 45^\circ$	$\pm 90^\circ$		$\pm 45^\circ$	$\pm 90^\circ$	$\pm 45^\circ$	$\pm 90^\circ$
Between conditions	11.18	23.54	4	2.80	5.86	1.98	5.44 **
Between subjects	776.42	998.46	204	3.81	4.89	1.92 *	4.79 *
Residual	<u>558.06</u>	<u>799.60</u>	<u>816</u>	1.46	1.02		
Totals	1345.66	1821.60	1024				

*(Significant at the 1 percent level of confidence 1.28, 204 and 816 d.f.)

**(Significant at the 1 percent level of confidence 3.35, 4 and 816 d.f.)

The value for (F) at 4 and 816 degrees of freedom would have to be greater than 2.58 to be significant at the 5 percent level of confidence. It would seem, therefore, that using the present experimental conditions and the criterion of ± 45 degrees that the (F) ratio of 1.98 indicates no differences due to the types of sounds used as stimuli. Subjects differed significantly, (F) of 1.92, in their ability to localize sound within an arc of 90 degrees.

The second analysis indicated that as the "correct" azimuth angle was increased from ± 45 degrees to a ± 90 degrees that the types of sounds used as stimuli differed significantly as to the frequency with which they were localized. The (F) ratio between sound conditions of 5.44, significant at the 1 percent level of confidence, makes untenable the hypothesis that sound types do not differ when observers attempt to localize them within a 180 degree arc. The (F) ratio indicating subject variance was also highly significant for the ± 90 degree criterion.

Because of the significant (F) found in the second analysis of variance above, (t) tests for related measures between the various types of stimulus sounds were made. The basic measures were the frequency with which the responses fell within ± 90 degrees. Reference to Table 3, showing the (t) ratios between the responses to the five types of stimulus sounds, indicates highly significant differences between Music and Continuous Speech (t of 4.538). There were significant differences between Music and [a] (t of 2.869), Music and Tone (t of 2.794) and Continuous Speech and White Noise (t of 3.192). The data do not show statistical differences between Music and White Noise or Tone and [a].

By inference, then, it would seem that the more complex sounds, i.e. Music and White Noise, are judged equally well and the simpler sounds of 500 cps Tone and [a] also judged equally well are different as to "accuracy" of localization within 180 degrees. If the evidence of the chi square test showing Music to be localized better than chance and the examination of the mean responses is admitted, it is possible to extrapolate that Music may be on one end of a continuum and Tone or [a] near the other.

Most of the investigators reporting previously on localization have indicated the difficulty experienced by observers in "hearing" the sounds directly in front of them or directly behind. Often they would judge the sound to be 180 degrees away from the stimulus. The frequency with which such direct reversals occurred in the present investigation were tabulated. Sixteen percent of all of the possible judgments fell into this category.

An examination of the response forms during tabulation indicated that there was no trend for one individual responding to the five types of sound stimuli to consistently make a direct reversal in localization. They appeared to be randomly distributed and not confined to the condition in which the sound stimulus came from directly in front or directly behind. A chi square test to determine the ratio indicating responses significantly better than chance yielded an χ^2 of 66.3, well beyond the 0.1 percent level of confidence.

$$\chi^2 = \frac{(980-768.75)^2}{768.75} + \frac{(5381.25-5170)^2}{5381.25} = 66.3$$

These results would seem to uphold the observation made by previous

investigations that direct reversal judgments occur frequently.

An informal observation was made during the time of processing the data. It was noted that when the stimuli were less intense, i.e. 2 and $2\frac{1}{2}$ feet from the loudspeaker, that the number of responses indicating no localization of the sound but centered within the head increased. Only infrequently did the individual make such a response when the microphones were at 8 inches or at 1 foot. The few "sophisticated" observers that listened prior to the more formal investigation had made opposite reports.

DISCUSSION

The results of the present experiment indicate that eliminating most of the cues to localization other than directing sounds to essentially the tympanic membrane widen the localization accuracy of azimuth angle previously reported. It seems that the next logical step would be to introduce some acoustical impedance, i.e. a shape representing a head, into the present system. It may be that some shape such as the head could, by modifying the phase and intensity relationships of the present equipment, provide additional cues for more accurate responses.

The present experimental setup should also provide a reasonable approach to a study of distance localization. The observers seemed to find that making two judgments on the response sheet used in the time interval of 5 seconds were all but impossible. A separate experiment in which distance is the sole response seems feasible, both with and without a simulated head interposed between the microphones of the two-channel system.

An additional group of studies that seem plausible using the high-fidelity stereophonic equipment would be amount, or degree, of movement of a sound stimulus in motion. The studies could be done with or without using a reference (stable angle) sound. Prior to any investigation regarding movement (apparent or actual) perhaps azimuth angle localization studies could be redone using a constant reference sound. These are a few of the studies that are possible using the present, or slightly modified equipment.

One of the circuit refinements that needs to be incorporated into the present system is a gate circuit to eliminate clicks that occurred infrequently in the present instrumentation. These extraneous noise "clicks" may have aided or hindered localization of the particular stimulus sound. The noises, however, occurred randomly and infrequently.

The results of the present experiment tend to support the theory that a more complex sound such as music stimulus can be localized more accurately than less complex sounds. The lack of a statistical difference between Music and White Noise lends further support. Contra-indications, however, are the wide differences in the (t) ratios between Tone - Music,

White Noise - Tone and Music - White Noise. The trend is toward more significant differences between a complex sound and a less complex, than between "simple" sounds or complex pairings.

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Table 1. Frequency, and the mean frequencies, with which 205 observers made on six judgments of each of five types of sound to fit four arbitrary response criteria.

<u>Response Criteria</u>	<u>500 cps</u>	<u>Prolonged [a]</u>	<u>Continuous Speech</u>	<u>Music</u>	<u>White Noise</u>	<u>Total</u>
Response falling within $\pm 45^\circ$ Mean	331 1.61	295 1.93	299 1.45	344 1.68	293 1.42	1562 1.52
Responses $> \pm 45^\circ$ but within $\pm 90^\circ$ Mean	184 .89	229 1.12	177 .86	252 1.23	260 1.27	1102 1.08
Responses falling within $\pm 90^\circ$ Mean	515 2.51	524 2.56	476 2.32	596 2.91	553 2.69	2664 2.60
Responses 180° from stimulus Mean	162 .79	242 1.18	227 1.11	208 1.01	141 .69	980 .96

Table 3. (t) ratios for related measures and the level of confidence for rejecting the null hypothesis between each of the five sound stimulus conditions when the basic measures were the frequency of the responses being "correct" \pm 90 degrees.

<u>Stimulus Sounds</u>	<u>(t) Ratio</u>	<u>Confidence Level</u>
music and continuous speech	4.538	0.1 percent
white noise and continuous speech	3.192	1.0 "
music and [a]	2.869	1.0 "
music and tone	2.794	1.0 "
white noise and tone	1.739	10.0 "
continuous speech and [a]	1.670	10.0 "
continuous speech and tone	1.639	20.0 "
white noise and [a]	1.143	30.0 "
tone and [a]	.070	above 30.0 "
music and white noise	.038	above 30.0 "

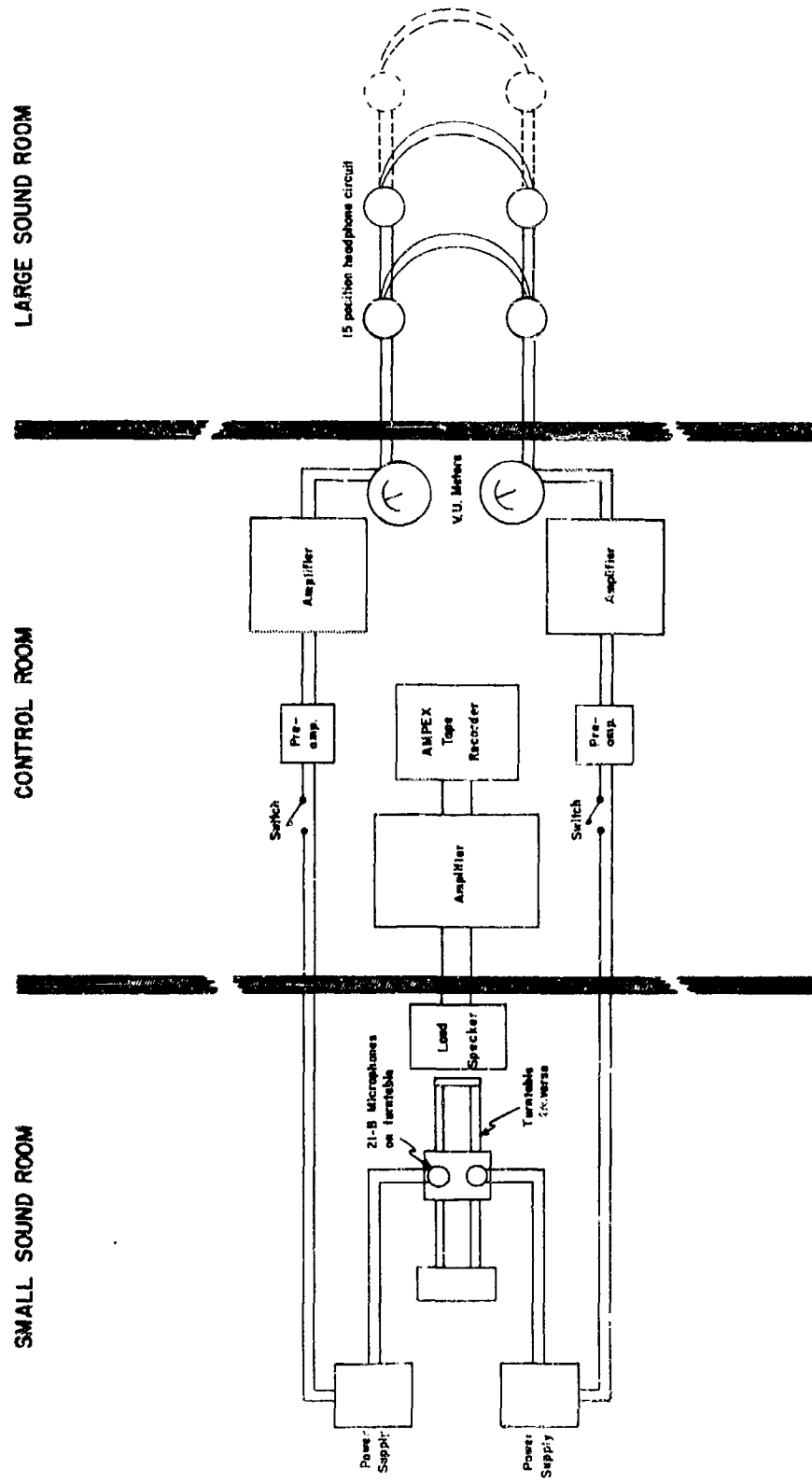


Figure 1 Block diagram of the dual-channel stereophonic sound system showing the components and their spatial relationships.

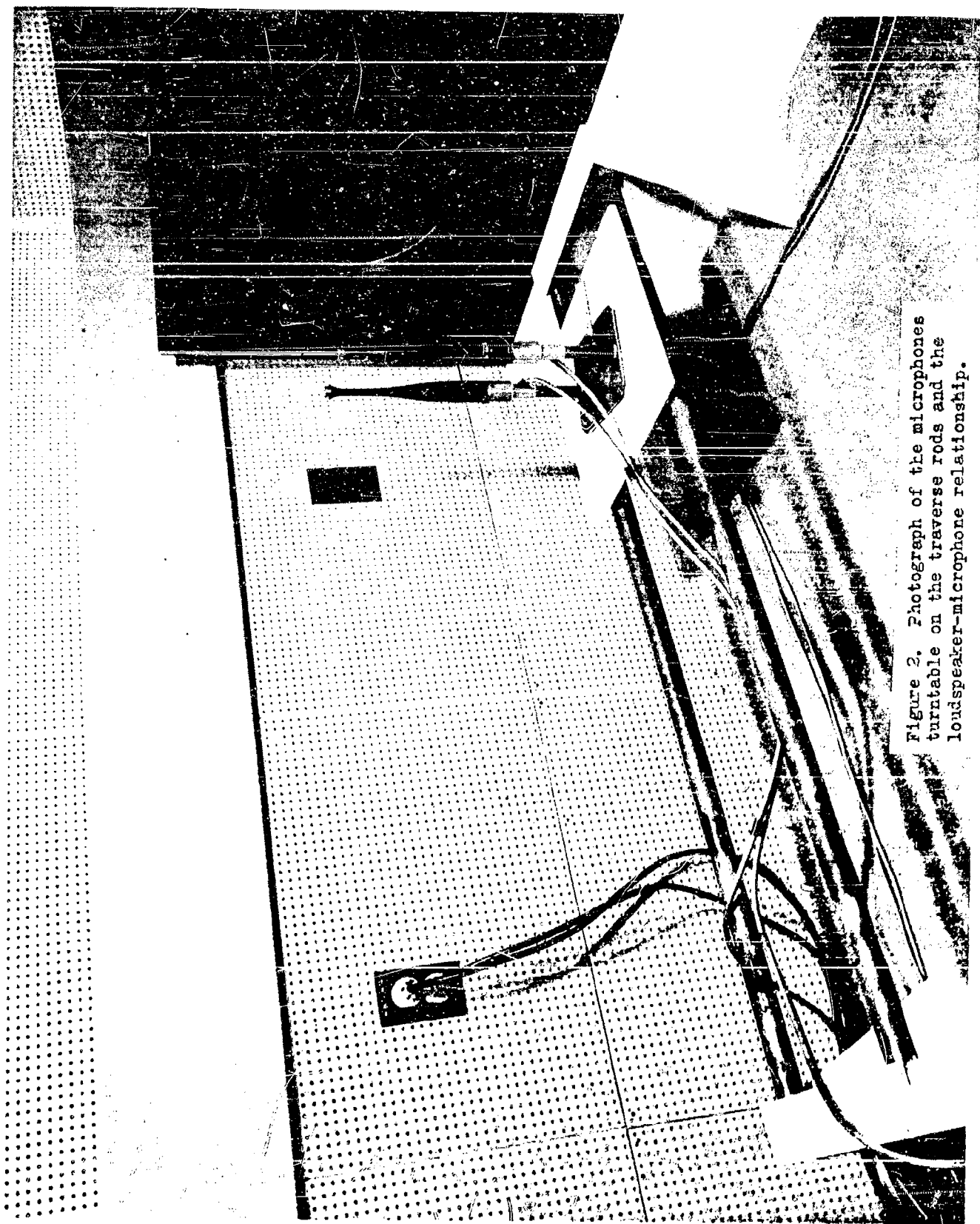


Figure 2. Photograph of the microphones
turntable on the traverse rods and the
loudspeaker-microphone relationship.

APPENDIX I

AZIMUTH AND DISTANCE SCHEDULE

1. Condition I - 500 cps tone

0° at 8"
225° at 3½'
90° at 2'
135° at 1'
45° at 8"
315° at 2'

4. Condition IV - Orchestral music

270° at 3½'
135° at 2'
270° at 1'
0° at 8"
315° at 8"
225° at 2'

2. Condition II - vowel [a] , sung

45° at 3½'
270° at 8"
180° at 1'
0° at 8"
315° at 2'
90° at 2'

5. Condition V - White noise

90° at 1'
45° at 8"
180° at 2'
135° at 2'
270° at 8"
225° at 3½'

3. Condition III - Continuous speech

225° at 8"
90° at 3½'
0° at 2'
315° at 2'
180° at 8"
45° at 1'

APPENDIX II

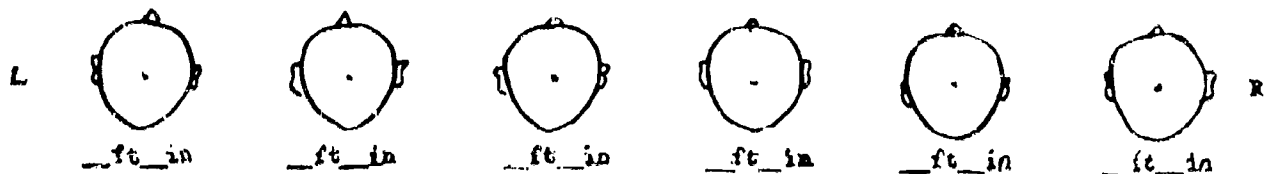
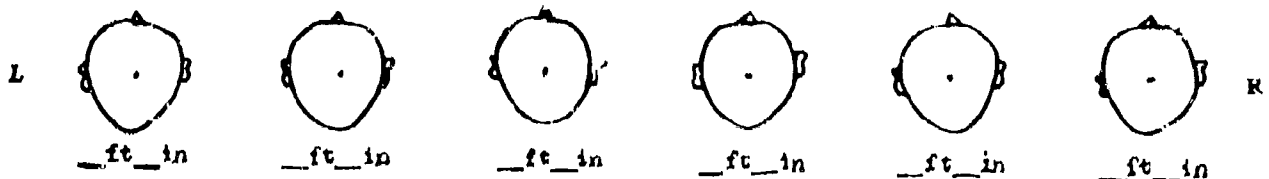
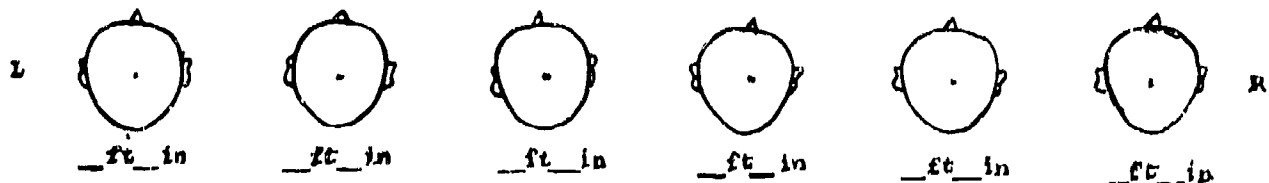
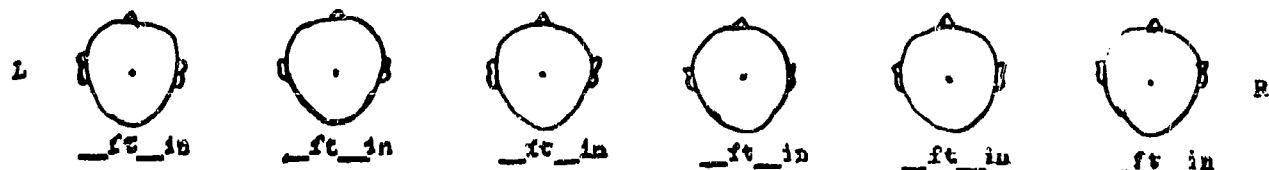
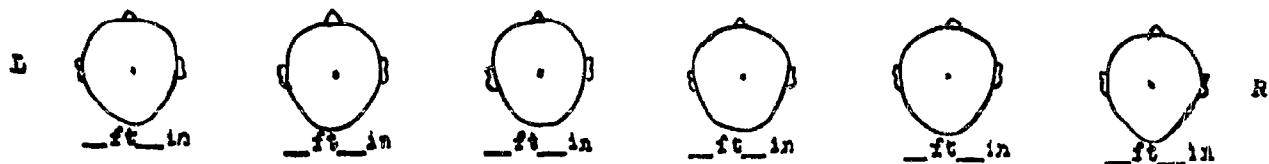
BINAURAL SOUND LOCALIZATION

NAME _____ Age _____ Date _____

Have you ever been exposed to prolonged gunfire _____?

Have you ever been exposed to prolonged aircraft noise _____? As pilot _____?

Ground crew or flight deck _____?



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